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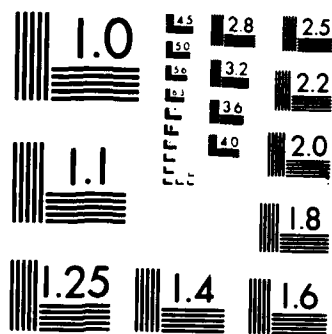   ELECTRONICS RESEARCH LAB S A MAAS 31 AUG 87
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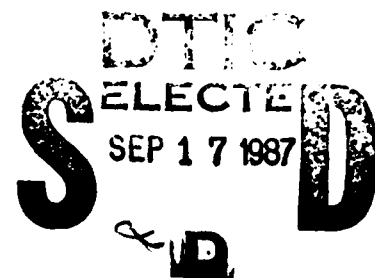
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REPORT SD-TR-87-39

AD-A184 848

A GaAs MESFET Balanced Mixer with Very Low Intermodulation

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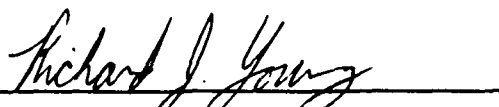
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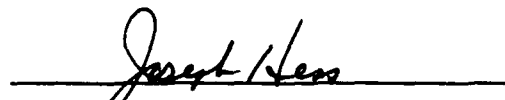
Capt Richard J. Young, SD/CWX, was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) Program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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A new type of balanced resistive mixer has been realized by using the unbiased channel of a GaAs MESFET as the mixing element. Because this resistance is only very weakly nonlinear, very low intermodulation results. State-of-the-art second- and third-order output intercept points of 34 and 21 dBm, respectively, are achieved, with a 7-dB conversion loss at X band.

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CONTENTS

FIGURES

I. INTRODUCTION

The Schottky-barrier diode used in most microwave mixers is one of the most strongly nonlinear devices found in microwave components; thus it is not surprising that diode mixers have relatively poor intermodulation (IM) and spurious-response properties. Methods to improve the IM performance of diode mixers have been proposed periodically,[1-4] but because of practical limitations, none have been widely accepted. However, it is not necessary to use a nonlinear device for a mixer; it is theoretically possible to realize an intermodulation-free mixer by using a time-varying linear resistor.

The mixer described here approximates a time-varying linear resistor, and achieves IM performance that far exceeds the state of the art for diode mixers. The resistance that realizes the mixing element is the very weakly nonlinear resistive channel of a GaAs MESFET; one makes this resistance time-variable by applying the local oscillator (LO) to the gate. Additionally, the mixer circuit is highly practical, simple, and easy to design, and has good conversion loss and good port impedances.

II. CIRCUIT DESIGN AND DESCRIPTION

Figure 1 shows the equivalent circuit of a MESFET without drain bias. The channel conductance $g(V_g)$ is weakly nonlinear, and is directly controlled by the internal gate/source voltage V_g. At zero drain voltage the gate-depletion capacitance is divided equally between the gate-source capacitance C_{gs} and the gate-drain capacitance C_{gd}. The gate, drain, and source resistances, R_g, R_d, and R_s, respectively, are the same as in the biased device.

To realize a mixer, one applies the LO and dc bias to the gate, and RF to the drain. The IF output is filtered from the drain. The large value of C_{gd} is a potential problem, however: first, because it reduces RF/LO isolation, and second, because it couples LO voltage to the drain and RF voltage to the gate. The LO voltage coupled to the drain swings the drain voltages over a more strongly nonlinear range, exacerbating IM generation, and the RF coupled to the gate may also increase IM as a result of transconductance nonlinearities. Therefore, in order to optimize IM performance, the LO is short-circuited at the drain, and the RF is short-circuited at the gate. The short circuit can be realized by the use of filters or a balanced structure.

The mixer circuit is shown in Fig. 2. It was designed to operate at 10 GHz with an IF of 10 to 100 MHz. The two FETs (packaged Avantek type AT10650) were chosen from the same processing lot of devices, and were checked to ascertain that their I/V characteristics were well matched. The FET gates must be driven with a 180-degree LO phase difference; this phase split is achieved by means of a loop of transmission line 180 degrees long. The drains are in parallel at the RF, and are fed through a quarter-wave transformer that matches the 50-ohm RF input to the 25-ohm input impedance of the parallel channels. The small reactive part (due to C_{gd}) of the input impedance is tuned out empirically. The IF currents in the channels are 180 degrees out of phase, and are therefore combined with a miniature RF transformer (Mini-Circuits type T4-1). The IF transformer also applies a near-optimum IF load impedance of 100 ohms to
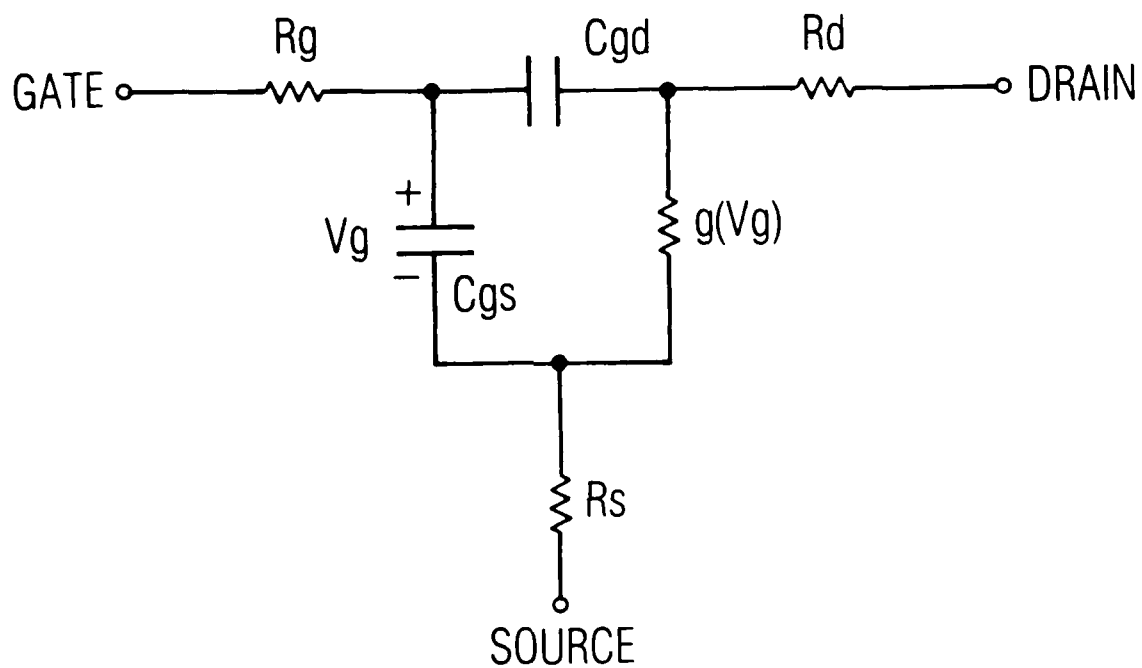
Fig. 1. Equivalent Circuit of a GaAs MESFET with No Bias
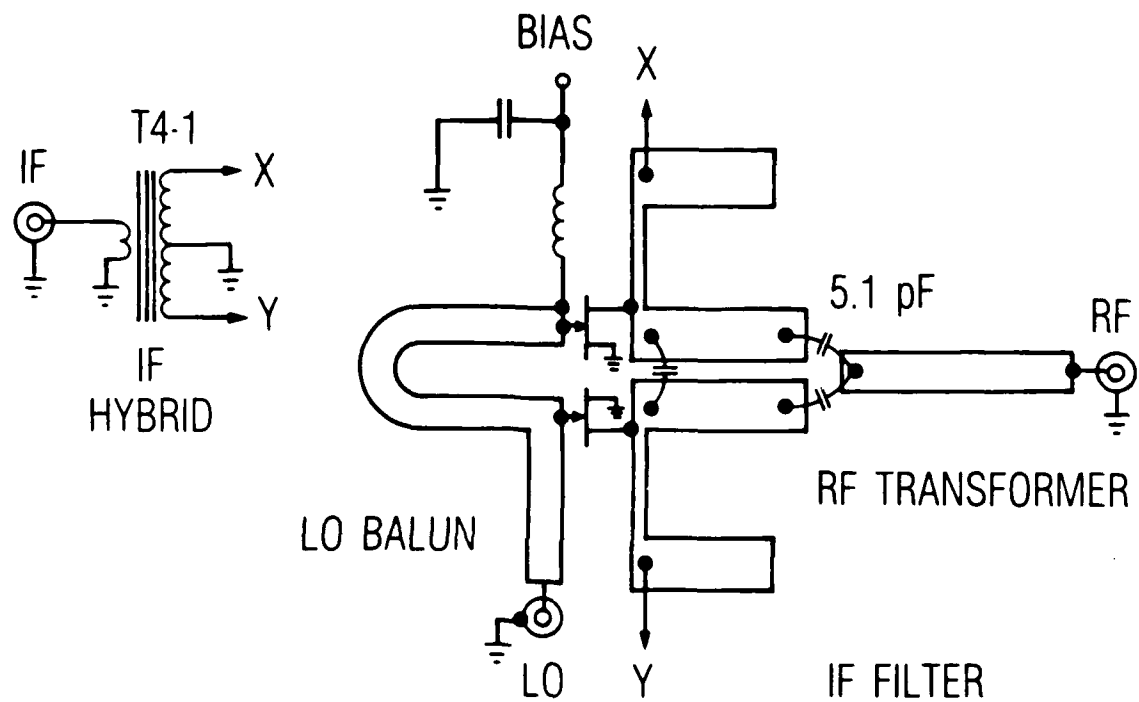Applied to the Drain

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Fig. 2. Circuit of the Balanced Mixer. All capacitors are
5.1 pF.

each FET; its loss is approximately 1 dB at 100 MHz.

The geometry of the circuit supplies the desired RF and LO short circuits to the gate and drain. Because of the 180-degree phase difference of the LO currents through C_{gd} in the two FETs, the drain node is a virtual ground to the LO. Similarly, the LO balun presents a short circuit to even-mode inputs such as the RF leakage. Many commonly used baluns, such as the Marchand balun used in doubly balanced diode mixers, may not be suitable here, because they present an open circuit to even-mode inputs.

III. PERFORMANCE

Figures 3a and 3b show the passband of the mixer for fixed IF and fixed LO. At a fixed IF frequency, conversion loss averages 7.0 dB over a 1-GHz band, including the 1-dB loss of the IF hybrid. The shape of the IF passband is determined primarily by the IF transformer. This performance is as good as that of most commercially available balanced-diode mixers.

Figure 4 shows the conversion loss as a function of LO power and gate bias, and Fig. 5 shows the corresponding IM levels. Higher gate bias gives better IM performance, although at lower LO power levels it is better to use somewhat lower bias. Lower bias also reduces the sensitivity of conversion loss to LO power. The sensitivity of both conversion loss and IM level to LO level is significantly lower than that of most commercially available diode mixers.

Figure 6 shows the second- and third-order IM levels as a function of RF level (the second-order component is the IF output at the difference between the two input frequencies). The second-order component exhibits the expected 2-dB/dB slope; however, the third-order output has a slope of 2.6 dB/dB at low RF levels and rises monotonically at high input levels. This result is not unusual, and indicates that nonlinearities of degree higher than three contribute significantly to third-order IM generation. Under these circumstances it is difficult to define an intermodulation intercept point, but over this range of power levels the IM level is lower than would be indicated by a third-order intercept point at a 21-dBm output. The second-order output intercept point from Fig. 6 is 34 dBm.
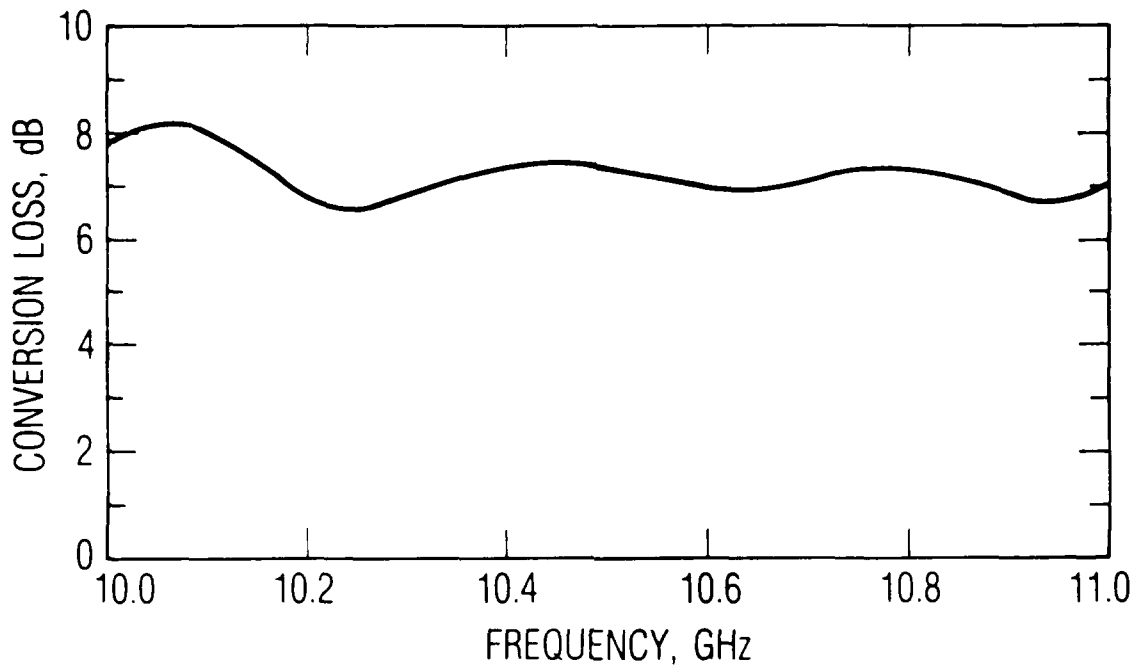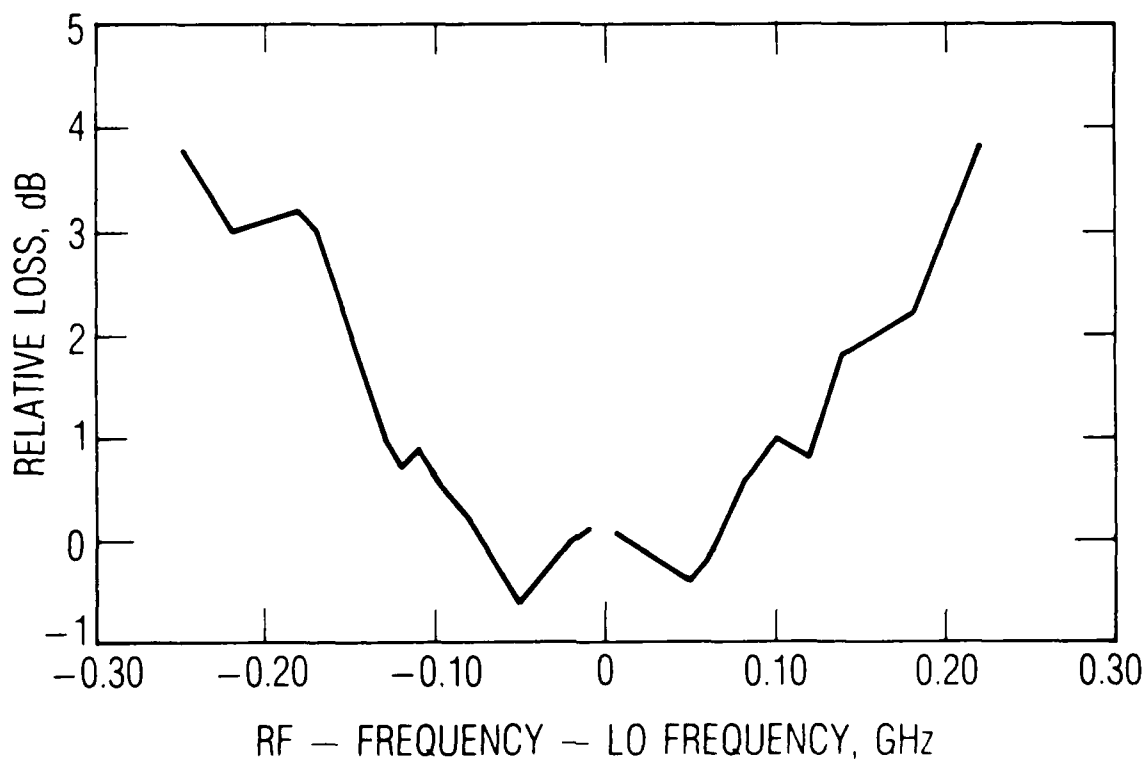
Fig. 3. Mixer Passband (a) with a Fixed IF Frequency and (b) with a Fixed LO Frequency
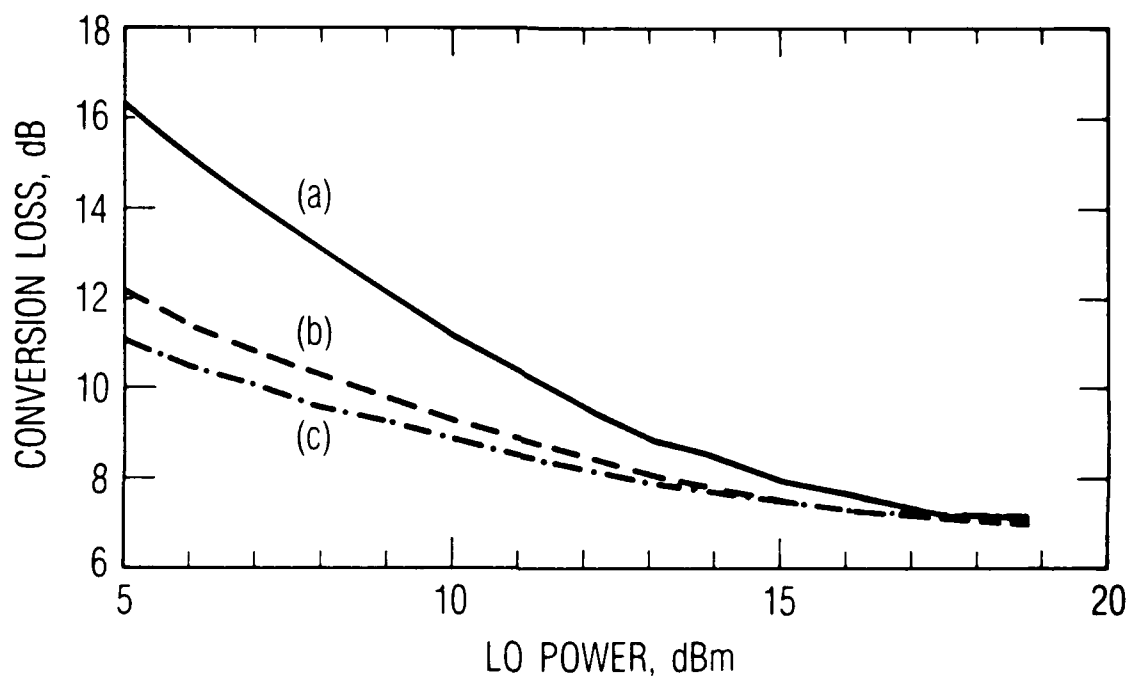
Fig. 4. Conversion Loss as a Function of LO Power and Gate
Bias. (a) V_{gs} = -1.10. (b) V_{gs} = -0.84.
(c) V_{gs} = -0.63.

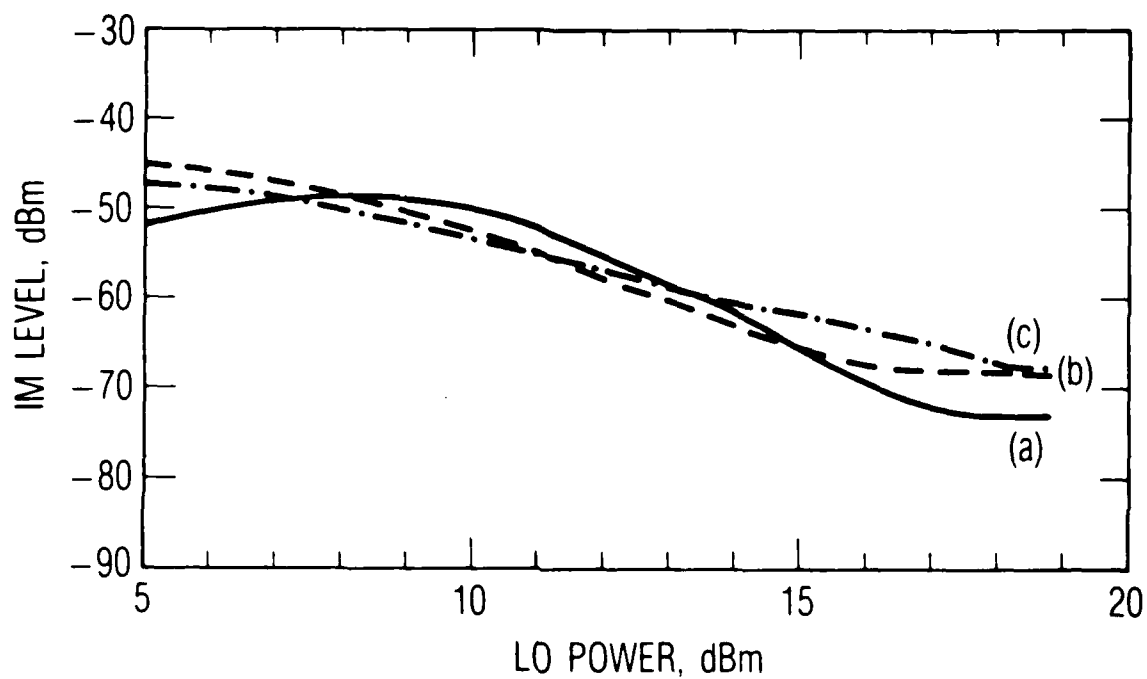Fig. 5. IM Level as a Function of LO Power and Gate Bias.
RF level is -3 dBm. (a) V_{gs} = -1.10. (b) V_{gs} =
-0.84. (c) V_{gs} = -0.63.

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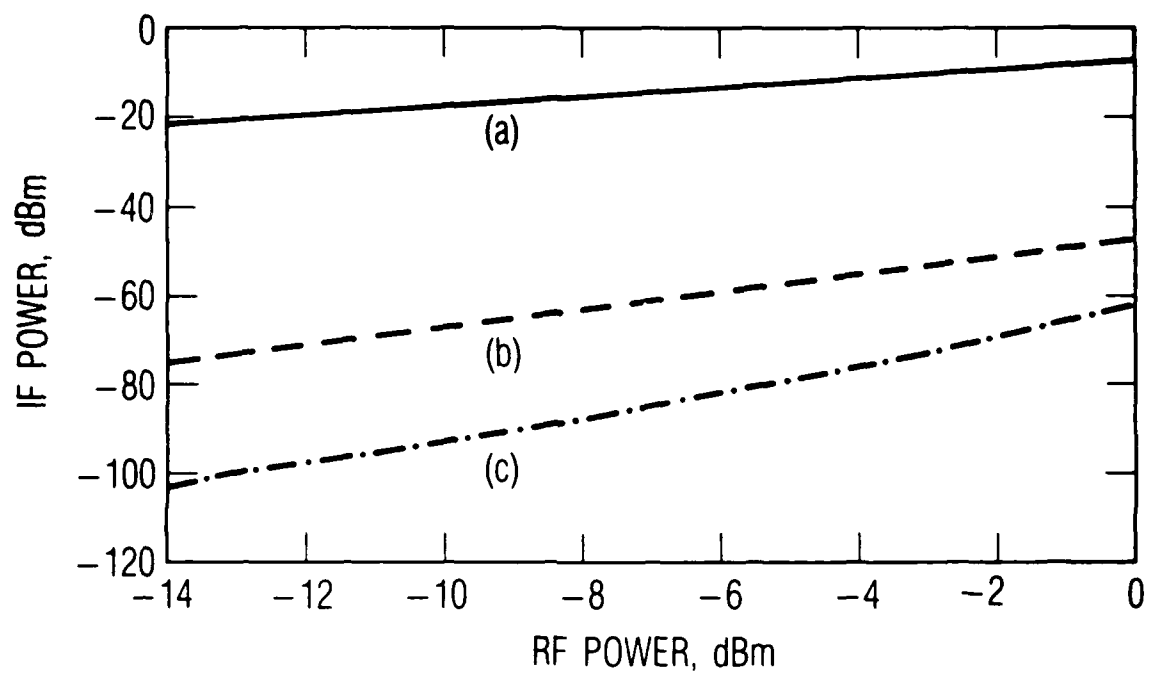
Fig. 6. (a) Linear, (b) Second-Order, and (c) Third-Order IM
Levels vs. RF Level

IV. CONCLUSION

A simple balanced-mixer circuit that uses the resistive channel of a GaAs MESFET exhibits intermodulation performance that exceeds the state of the art for commercially available diode mixers. Other performance parameters, e.g., conversion loss, port impedances, and LO sensitivity, are equal to or better than those of such diode mixers.

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LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

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